3.3 EVERGLADES AGRICULTURAL AREA

Introduction

A strong interaction exists between the hydrologic and management processes in the Everglades Agricultural Area. This section focuses on the calculation of ET in the EAA as it relates to the estimation of runoff and demand (irrigation requirement) in the EAA. Initially, a general description of the region is given. A discussion of the simulation of runoff and demand follows. Lastly, EAA canal routing will be explained as it relates to conveyance considerations in the EAA.

General Description

The Everglades Agricultural Area (EAA) encompasses an area south and southeast of Lake Okeechobee (Fig. 3.3.1), covering approximately 593,000 acres of land of which 468,000 acres are in agricultural production (1988 land use cover information). Of the area in agricultural production, about eighty percent is sugar cane. The four primary conveyance canals within the EAA are the Miami, North New River, Hillsboro and West Palm Beach Canals. They are used both for water supply and flood control purposes. The major structures in the EAA are S-3/S-354, S-2/S-351, S-352, S-4, S-5A, S-6, S-7, and S-8 (Fig. 3.3.1). The Rotenberger Tract and Holey Land, although part of the Miami Canal basin, are separated from the irrigated areas by levees, and thus, are treated as separate subbasins in the model. The following discussion will focus on the Miami, North New River/Hillsboro and West Palm Beach Canal basins. Figure 3.3.2 conceptualizes inflows and outflows from the EAA. The SFWMM simulates discharges at all inlet and outlet structures shown in Fig. 3.3.2 except G-88 and G-136 at which historical estimates are used to provide boundary flows into the EAA from Hendry county.

Unique characteristics of the EAA are as follows:

1. Extensive field-scale management operations within the EAA are simplified such that they fit within the regional-scale modeling framework of the SFWMM. Water levels within the EAA are well-maintained below land surface due to seepage irrigation. Thus, overland flow is not calculated between grid cells within the EAA although infiltration, evapotranspiration and groundwater flow are still simulated as distributed processes within the same area.

2. Discharges from the lake into the EAA and into the WCAs through the EAA canals are influenced by operating rules in the EAA, as well as by those in Lake Okeechobee and the Water Conservation Areas.

3. The amount of water that can flow through the EAA is constrained by EAA canal conveyance characteristics, and local runoff and demand conditions.

4. Flowthrough capacity along an EAA canal, i.e., the amount of lake water that can be delivered south into the Water Conservation Areas, depends on EAA canal conveyance characteristics. The latter, in turn, is a function of the EAA canal water surface profile. Therefore, a hydrodynamically-based routing procedure where the water surface profile and corresponding discharge is calculated for the EAA is necessary in order to account for the daily variation of EAA flowthrough capacity. This procedure is different from the water budget approach applied to non-EAA canals where a hydraulic grade line with time-invariant slope is assumed.

5. Limited or sparse stage and rainfall data exists for the interior part of the EAA such that calibration by matching historical stages is not possible at this point in time.

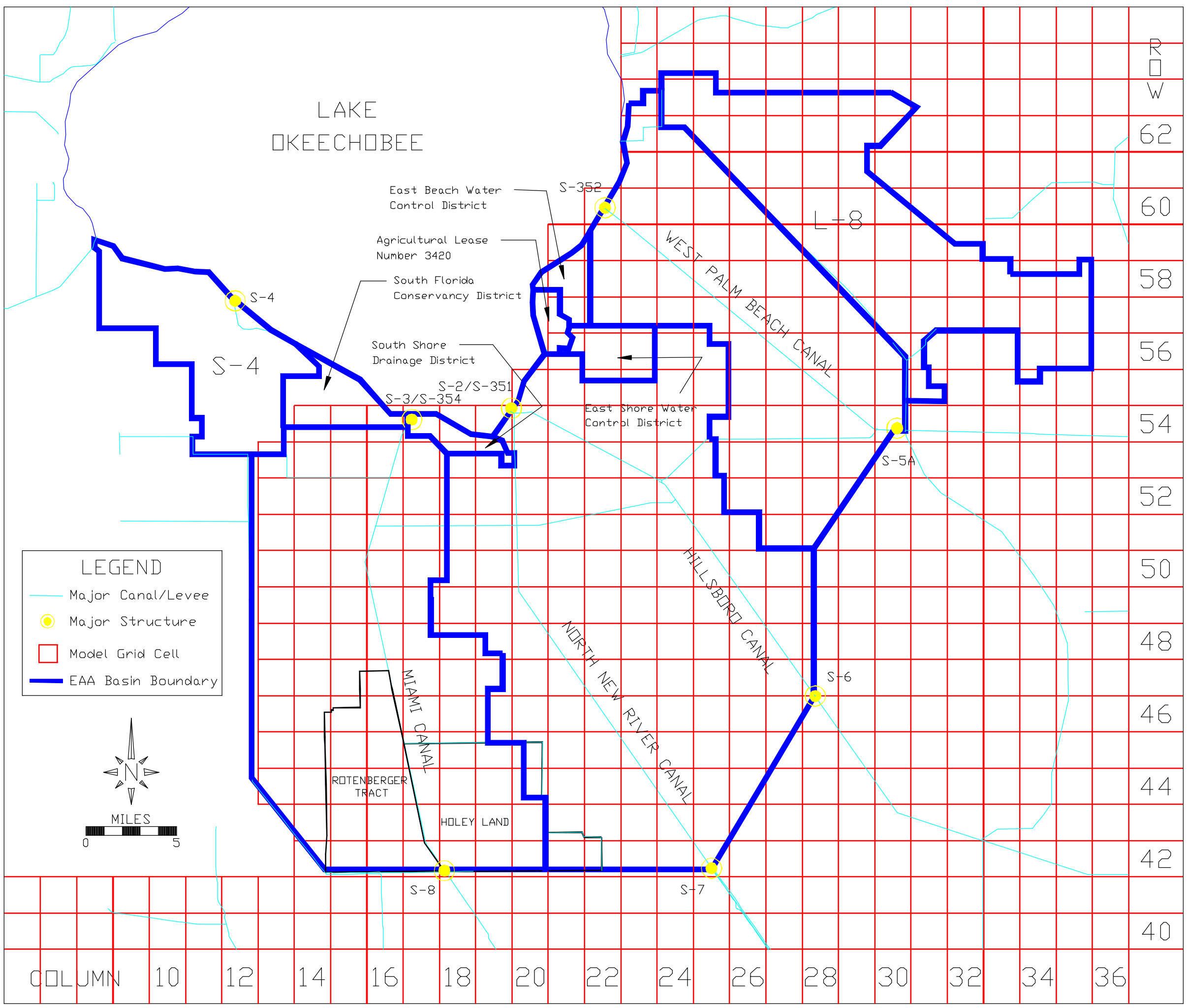


Figure 3.3.1 South Florida Water Management Model Grid Superimposed on Major Basins in the Everglades Agricultural Area

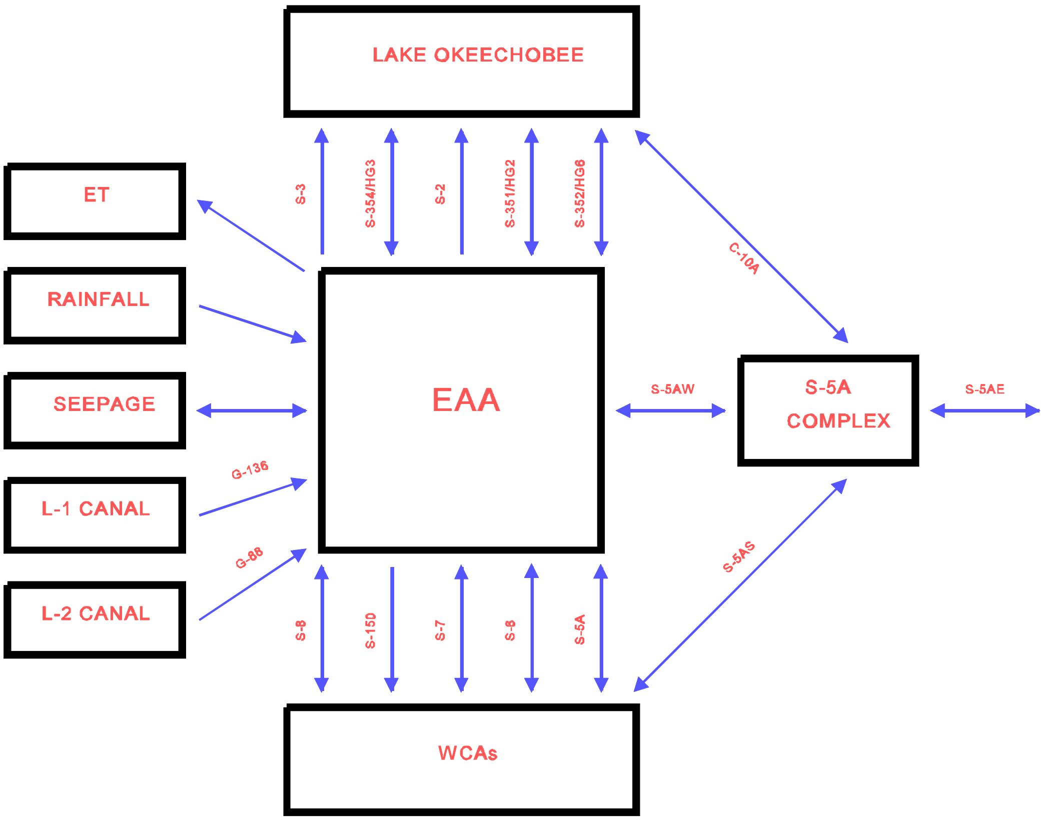


Figure 3.3.2 Conceptual Diagram of the Hydrologic System in the Everglades Agricultural Area as Represented in the South Florida Water Management Model (adapted from Abtew and Khanal, 1992)

Simulation of EAA Runoff and Demand

The EAA is a system with limited storage capacity. Runoff occurs in times when rainfall exceeds storage capacity and irrigation requirements in the area. Irrigation requirement, on the other hand, is the amount of water in excess of rainfall needed to satisfy evapotranspiration requirements within the EAA. In the soil moisture balance model discussed in the EAA report by Abtew and Khanal (1992), the entire area of the EAA in production was assumed to have a uniform depth to water table equal to 1.5 feet below land surface. This is consistent with the level at which the water table is maintained in the EAA during seepage irrigation, the type of irrigation used for the predominant crop type in the area, sugar cane. Within this narrow band of soil, referred to as the *soil column* (A in Fig. 3.3.3), a desired range of moisture contents is maintained. The lower and upper limits of this range (C and D in Fig. 3.3.3) expressed in terms of equivalent depths of water are SOLCRT and SOLCRNF, respectively.

Therefore, the EAA is simulated in the model such that the natural fluctuation of total soil moisture above the water table is within SOLCRT and SOLCRNF. Also, the water table is maintained at 1.5 feet below land surface.

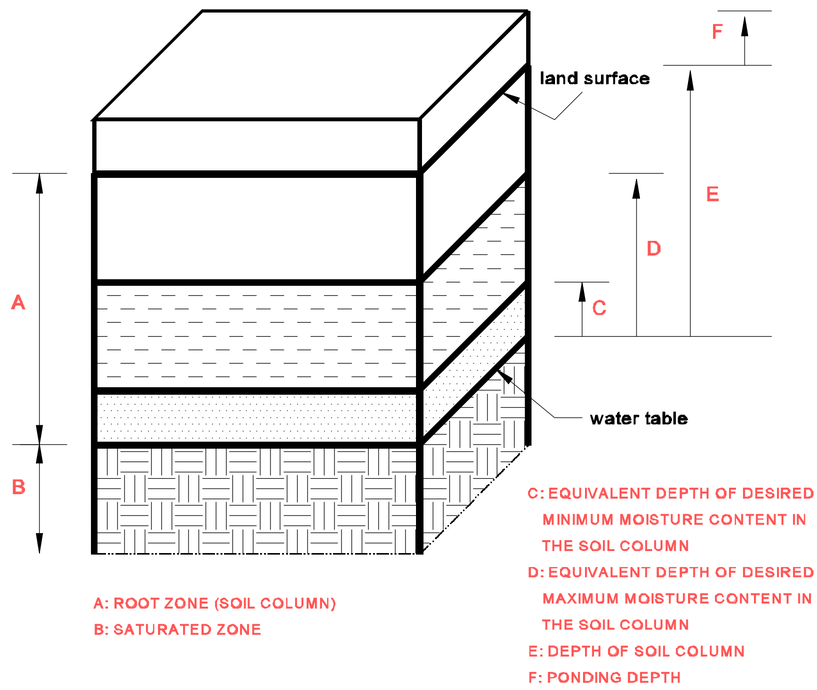


Figure 3.3.3 Conceptual Representation of an EAA Grid Cell in the SFWMM

A definition of some pertinent variables used in simulating runoff and irrigation requirements in the EAA is given below:

DPH	=	depth of irrigation requirement;
depth_soil_eaa	=	assumed distance between land surface and the water table; thickness of the soil column; equal to 1.5 ft;
DPTHRNFF	=	potential depth of runoff initially equal to the sum of POND and SOLMX in excess of SOLCRNF;
ELLS	=	land surface elevation relative to NGVD;
ET	=	total evapotranspiration from ponded water, and moisture in the unsaturated and saturated zones;
	=	ETP + ETU + ETS;
fracdph_max	=	ratio of maximum equivalent depth of water that can be stored in the soil column and equivalent depth of desired maximum moisture content in the same soil column; used as a calibration parameter (refer to Chap. 4)
fracdph_min	=	ratio of maximum equivalent depth of water that can be stored in the soil column and equivalent depth of desired minimum moisture content in the same soil column; used as a calibration parameter (refer to Chap. 4)
GDAR	=	grid cell area;
GWMAXDP	=	equivalent depth of water required to fill the storage space below the base of the soil column to the water table plus meeting anticipated saturated zone evapotranspiration;
H	=	head; location of the water table relative to NGVD;

PERC = water that goes to the saturated zone from ponding and excess moisture in the soil column used to raise the water table up to the base of the soil column;
PERC_IRRIG = water that goes to the saturated zone from irrigation used to raise the water table up to the base of the soil column;
POND = ponding depth;
RAIN = depth of rainfall;
S = storage coefficient; typically 0.20;
SOLCRNF = equivalent depth of desired maximum moisture content in the soil column a calibration parameter that varies with month of year;
= fracdph_max * depth_soil_eaa * S;
SOLCRT = equivalent depth of desired minimum moisture content in the soil column; trigger for irrigation requirements to be met from outside sources (e.g., LOK); a calibration parameter that varies with month of year;
= fracdph_min * depth_soil_eaa * S;
SOLMDPH = maximum equivalent depth of water that can be stored in the soil column; storage capacity of the soil column;
= depth_soil_eaa * S;
SOLMX = equivalent depth of soil moisture in the soil column;
VOL_EXCESS_WATER = volume of excess water that runs off from an EAA grid cell equal to the product of DPTHRNFF and GDAR; and
VOL_IRRIG = volume of irrigation requirement for an EAA grid cell equal to the product of DPH and GDAR.

The following sequence of calculations is performed for each EAA grid cell at each time step. Evapotranspiration is calculated first. Assuming unrestricted supply of water at all times, either through available moisture in the root zone, rainfall or irrigation, the theoretical crop requirement is given by

$$ETMX = KCALIB * KVEG * PET_0 \tag{3.3.1}$$

where:

PET_0 = depth of potential evapotranspiration for a reference crop (turfgrass) calculated using a modified Penman-Monteith method;
KVEG = theoretical crop coefficient which are monthly averaged values; KVEG was based on an earlier study (Abtew and Khanal, 1992). In the EAA, only the predominant crop type: truck crops, sugar cane or irrigated pasture is assigned to each cell.; and
KCALIB = adjustment/calibration parameter which varies from month to month; KCALIB was created to take into account differences between modeling approaches, specifically modeling scale, used in the soil moisture balance model by Abtew and Khanal (1992) and the South Florida Water Management Model.

Table 3.3.1 shows the monthly variation of theoretical crop coefficient KVEG for the three predominant crop types in the EAA. Note that the final/calibrated KVEG values for land use types 7, 8 and 9 in Table 2.2.3 correspond to the product of the theoretical KVEG and the adjustment/calibration parameter KCALIB discussed in this section.

Table 3.3.1 Monthly Theoretical Crop Coefficient KVEG for the Three Predominant EAA Crop Types

Month	Truck Crops	Sugar Cane	Irrigated Pasture
January	0.64	0.80	0.65
February	0.69	0.60	0.70
March	0.87	0.55	0.75
April	0.95	0.80	0.95
May	0.86	0.95	0.95
June	0.66	1.00	0.98
July	0.61	1.05	0.98
August	0.66	1.05	0.98
September	0.71	1.05	0.94
October	0.87	1.00	0.80
November	0.93	0.95	0.87
December	0.88	0.90	0.65

Total evapotranspiration depth, on the other hand, is given by

$$ET_0 = KFACT * PET_0 \qquad (3.3.2)$$

where KFACT is an adjustment factor that takes into account vegetation/crop type and location of the water table relative to land surface. Table 3.3.2 shows the adjustment factor KFACT as a function of depth. Note that ETMX corresponds to ET_0 evaluated at land surface down to the depth to shallow root zone. A definition of some variables introduced in Table 3.3.2 is given below:

OWPOND = ponding depth above which open-water ET exists; Transpiration by plants submerged at depths equal to or more than OWPOND no longer contribute to evapotranspiration, and evapotranspiration is equal to open-water evaporation; OWPOND is assigned a value of 12 in. in the model.;

DSRZ = depth from land surface to the bottom of the shallow root zone; depth below which the root system of a crop will experience increased difficulty in extracting water from the saturated zone; equal to 18 in.;

DDRZ = depth from land surface to the bottom of the deep root zone; depth below which the root system of a crop can no longer extract water from the saturated zone; assumed to be between 36 to 46 in.;

PND = depth of ponding;
DWT = distance of water table below land surface; and
KMAX = conversion factor from PET_0 to open water ET; assumed to be equal to 1.1.

Table 3.3.2 Variation of KFACT in the Equation for Theoretical Total Evapotranspiration as a Function of Depth

Depth from Land Surface to Water Line DWT: water table condition (below ground) PND: ponding condition (above ground)	**Adjustment Factor, KFACT**
DWT $\geq$ DDRZ	0.0
DSRZ < DWT < DDRZ	[(DDRZ-DWT)÷(DDRZ-DSRZ)] * KVEG*KCALIB
0 $\leq$ DWT $\leq$ DSRZ	KVEG*KCALIB
0 < PND $\leq$ OWPOND	(KMAX-KVEG*KCALIB)*PND÷OWPOND + KVEG*KCALIB
PND > OWPOND	KMAX

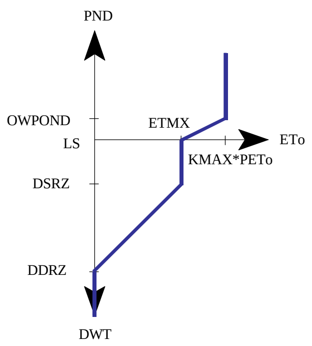


Figure 3.3.4 Variation of Total Evapotranspiration, ET_0 , as a Function of Depth

Figure 3.3.4 is a diagram of the total evapotranspiration as it varies with depth. The actual total evapotranspiration (ET) is the sum of three components: ETS from the saturated zone, ETU from the unsaturated zone, and ETP from free water zone or ponding. The model assumes that evapotranspiration is extracted from the unsaturated zone first, and the free water zone last. Initially, ponding and rainfall are assumed to increase moisture in the soil column. Unsaturated zone evapotranspiration then becomes the lesser value between the theoretical crop requirement [Eq. (3.3.1)] and the total available moisture in the soil column.

$$ETU_t = \min [ETMX_t, POND_{t-1} + RAIN_t + SOLMX_{t-1}] \qquad (3.3.3)$$

The remaining theoretical requirement, $ETMX_t$ - ETU_t, if any, will be met from the water table. This amount is limited by the remaining theoretical total evapotranspiration. The anticipated evapotranspiration from the saturated zone is

$$ETS_t = \min [ETMX_t - ETU_t, ETS_0] \qquad (3.3.4)$$

where ETS_0 is the theoretical saturated zone ET. It is essentially the same as ET_0 defined at depths below land surface (LS in Fig. 3.3.4). Evapotranspiration from ponding becomes

$$ETP_t = \min [ET_0 - ETMX, POND_t] \qquad (3.3.5)$$

For accounting purposes, the following equalities are assumed for ponding and non-ponding conditions:

1. If ponding exist:
$ET = ET_0$, $ETU = ETMX$, $ETS = 0.0$, and $ETP = ET - ETU$.

2. If there is no ponding:
ETU from Eq. (3.3.3), ETS from Eq. (3.3.4), $ETP = 0.0$, and $ET = ETU + ETS$.

The soil moisture content expressed in terms of equivalent water depth above the base of the soil column is calculated next:

$$SOLMX_t = SOLMX_{t-1} + POND_{t-1} + RAIN_t - (ETU_t + ETP_t).$$

If the updated soil moisture content exceeds the storage capacity of the soil column, SOLMDPH, ponding will result at the end of the time step and soil moisture have to be reevaluated. Thus,

$$POND_t = \max [SOLMX_t - SOLMDPH, 0.0] \qquad (3.3.6)$$

$$SOLMX_t = SOLMDPH \quad \text{if} \quad POND_t > 0. \qquad (3.3.7)$$

The potential depth of runoff, DPTHRNFF, equals the ponding depth plus any soil moisture beyond the equivalent depth of the desired maximum moisture content in the soil column, SOLCRNF. (note: SOLCRNF $\leq$ SOLMDPH).

$$DPTHRNFF_t = \max [POND_t + SOLMX_t - SOLCRNF, 0.0]$$

So far, this amount of potential runoff assumes that the water table is already at 1.5 feet below land surface elevation. An assumption in the simulation of the EAA in the SFWMM is that ponded water and moisture in the unsaturated zone percolates into the saturated zone up to the base of the soil column, if necessary, before runoff actually occurs. DPTHRNFF is reduced by the amount of percolation or the amount of water needed to bring the water table at 1.5 feet below land surface. In other words, if the water table is below the base of the soil column, the potential depth of runoff will be used to fill the available storage in the form of percolation. The concept of maintaining the water table at 1.5 feet below land surface, and the specification of the desired minimum and maximum moisture content (in terms of equivalent depth) above the water table are key modeling techniques used to simulate runoff and quantify irrigation requirements (demands) in the EAA module of the SFWMM.

Actual percolation is the lesser value between what could potentially runoff, DPTHRNFF, and the amount of water necessary to bring the water table up to the base of the soil column, GWMAXDP. Assuming that the water table is below the base of the soil column, GWMAXDP represents the available storage between the base of the soil column and the water table plus anticipated saturated zone ET. It can be calculated as follows. The vertical distance between the water table and the base of the soil column, WT_TO_BSC, is given by

$$WT\_TO\_BSC_t = (ELLS - SOLMDPH \div S) - H_t.$$

Note that SOLMDPH÷S is equal to 1.5 ft, and WT_TO_BSC is greater than zero if the base of the soil column is above the water table.

$$EQUIV\_DEPTH\_SOIL\_COL\_TO\_WT_t = \max [WT\_TO\_BSC_t * S, 0]$$

$$GWMAXDP_t = EQUIV\_DEPTH\_SOIL\_COL\_TO\_WT_t + ETS_t$$

$$PERC_t = \min [DPTHRNFF_t, GWMAXDP_t] \quad (3.3.8)$$

The updated potential depth of runoff becomes

$$DPTHRNFF_t = DPTHRNFF_t - PERC_t \quad (3.3.9)$$

while the remaining storage below the base of the soil column that needs to be filled in from other sources (specifically, via irrigation) is

$$GWMAXDP_t = GWMAXDP_t - PERC_t. \quad (3.3.10)$$

It should be noted that $GWMAXDP_t$ can be positive only if $DPTHRNFF_t = 0$ after Eq. (3.3.9). In other words, DPTHRNFF and GWMAXDP are mutually exclusive, i.e., they cannot be non-zero at the same time.

The model assumes that the portion of the potential depth of runoff that comes from ponding percolates below the soil column before soil moisture in excess of SOLCRNF does. Therefore, if the amount of water that percolates is greater than $POND_t$, then, all of ponding is assumed to percolate and soil moisture is reduced. $SOLMX_t$ and $POND_t$ are updated within the current time step t.

$$SOLMX_t = SOLMX_t - [PERC_t - POND_t] \quad (3.3.11)$$
$$POND_t = 0. \quad (3.3.12)$$

Otherwise, $POND_t$ is reduced while $SOLMX_t$ remains the same.

$$POND_t = POND_t - PERC_t \quad (3.3.13)$$

If, at this point in the algorithm, the updated potential depth of runoff, $DPTHRNFF_t$ in Eq. (3.3.9), is still positive, it implies that the water table is already at the base of the soil column and no irrigation is required for this EAA grid cell. $DPTHRNFF_t$ will, indeed, leave the grid cell and the final ponding above land surface and final soil moisture in the soil column are computed using the following three equations.

$$SOLMX_t = SOLMX_t + POND_t - DPTHRNFF$$
$$POND_t = \max [SOLMX_t - SOLMDPH, 0] \quad (3.3.14)$$
$$SOLMX_t = SOLMX_t - POND_t \quad (3.3.15)$$

And the volume of excess water leaving the grid cell becomes

$$VOL\_EXCESS\_WATER = DPTHRNFF * GDAR. \qquad (3.3.16)$$

If, on the other hand, the updated potential depth of runoff, $DPTHRNFF_t$, is zero, it implies that: (1) ponding is zero; (2) irrigation may be required to bring the water up to the bottom of the soil column and/or maintain an equivalent depth of minimum moisture content SOLCRT in the soil column; and (3) the water table may still be below the base of the soil column. (note: SOLCRT $\leq$ SOLCRNF)

The irrigation requirement is calculated next. The total required storage depth for irrigation is

$$TOTAL\_DEPTH = GWMAXDP + DEPTH\_BELOW\_MIN \qquad (3.3.17)$$

The first term in the above equation, GWMAXDP, represents the equivalent depth of water required to maintain the saturated zone. The second term, DEPTH_BELOW_MIN, is the equivalent depth of water required to maintain minimum moisture content in the unsaturated zone. It is calculated as

$$DEPTH\_BELOW\_MIN = \max [SOLCRT - SOLMX_t, 0].$$

By definition, the depth of irrigation requirement, DPH, is equal to the lesser value between the net theoretical crop evapotranspiration requirement ($\max[ETMX-RAIN_t, 0]$) and the total required storage depth for irrigation.

$$DPH = \min (\max[ETMX-RF_t, 0], TOTAL\_DEPTH) \qquad (3.3.18)$$

The model assumes that irrigation brings the soil moisture content in the soil column (unsaturated zone) up to the minimum level SOLCRT before percolation occurs. Percolation, at this point in the discussion, is the process by which water is introduced below the soil column via irrigation in order to bring the water table 1.5 feet below land surface. Therefore, the anticipated increase in soil moisture in the unsaturated zone, after irrigation, will be equal to the lesser of values between the depth of irrigation requirement and irrigation required to bring the soil content in the soil column to equivalent depth SOLCRT:

$$SOLMX_t = SOLMX_t + \min [DPH, DEPTH\_BELOW\_MIN] \qquad (3.3.19)$$

Finally, anticipated percolation due to irrigation can be calculated as that portion of DPH in excess of DEPTH_BELOW_MIN:

$$PERC\_IRRIG = \max [DPH - DEPTH\_BELOW\_MIN, 0] \qquad (3.3.20)$$

For a given EAA grid cell, the volume of irrigation requirement is given by

$$VOL\_IRRIG = DPH * GDAR. \qquad (3.3.21)$$

Routing of Excess Runoff

The above calculations are done for all cells in each EAA basin. On any given day, a grid cell may either have excess water or irrigation requirement but not both. The total net excess volume of water for a given basin j is given by the formula

$$NET\_EXCESS\_VOL_j = \sum_{i=1}^{nnodes_j} (VOL\_EXCESS\_WATER_i - VOL\_IRRIG_i) \qquad (3.3.22)$$

where:

j = 1 for Miami Canal basin;
= 2 for North New River/ Hillsboro Canal basin; and
= 3 for West Palm Beach Canal basin.

A positive total net excess volume of water for an EAA basin j is equal to what could potentially leave the basin. Thus, for a given time step, runoff from some cells are used to meet irrigation requirements in the other cells within the same basin and any net excess volume of water (potential excess runoff) can be routed out of the basin and into storage areas such as Lake Okeechobee and the Water Conservation Areas. The intrabasin transfer of the volume of excess water is not done based on the traditional channel routing or overland flow procedures but is performed by direct transfer of water. It is assumed that secondary and tertiary canal systems in the EAA have sufficient capacity to move this volume of water from appropriate cells into cells within the same basin that require irrigation within one time step.

In reality, the system may not be able to remove the entire net excess volume of water from a given EAA basin due to the following constraints:

1. Attenuation and lag effects in the secondary and tertiary canal systems cause actual excess runoff leaving a basin to be less than the potential excess runoff for the same day. Based on a comparison of simulated daily excess water with historical runoff from all EAA basins for the period 1983 through 1990, the actual excess runoff can be calculated as a fraction of the potential excess runoff which, in turn, is equal to the net excess volume calculated in Eq. (3.3.22). In effect,

$$\text{actual excess runoff} = FRACT * NET\_EXCESS\_VOL \qquad (3.3.23)$$

The reduction factor, FRACT, is a fraction that varies with the magnitude of potential excess runoff.

2. The design capacity of outlet structures limit the amount of excess runoff that can be removed from an EAA basin. Table 3.3.3 shows the operational constraints used in removing excess runoff for each EAA basin on a daily basis as implemented in the SFWMM. The empirical equations in the table are a result of a statistical analysis of available flow records for the major EAA structures.

Table 3.3.3 Operational Constraints Used in the SFWMM for Removing Excess Runoff from EAA Basins

EAA Basin	Flood Control Backpumping, BP, to LOK	Routing of Remaining EAA Runoff
Miami Canal Basin	BP = 80% of 7-day running mean daily runoff from basin in excess of 3200 cfs note: Backpumping is done through S-3. (S-3 capacity* = 2,600 cfs).	A maximum daily rate of 750 cfs to Holey Land, depending on Holey Land's stage relative to its schedule. The remainder goes to WCA-3A through S-8 (S-8 capacity* = 4,200 cfs).
North New River-Hillsboro Canal Basin	BP = 80% of 7-day running mean daily runoff from basin in excess of 4500 cfs note: Backpumping is done through S-2. (S-2 capacity = 3,600 cfs).	10% of runoff goes through S-150 into WCA-3A; 50% of runoff goes through S-7 into WCA-2A (S-7 capacity = 2,500 cfs); and 40% of runoff goes through S-6 into WCA-1 (S-6 capacity* = 2,900 cfs)
West Palm Beach Canal Basin	None	100% of runoff goes through S-5A pumps into WCA-1 (S-5A capacity = 4,800 cfs)
"298" Districts	All potential excess runoff pumped into Lake Okeechobee (capacity = 750 cfs)	None

* rounded-off to the nearest 100 cfs

The actual transfer of water is performed in subroutine ROUTE while the adjustment of water levels and soil moisture is done in subroutine AGAREA. Rotenberger Tract and Holey Land, although part of the Miami Canal Basin, are separated from the irrigated areas by levees, and are treated as separate basins in the model. Any net runoff in excess of structure design capacities is returned uniformly to all grid cells within the appropriate basin. Currently, interbasin transfers of runoff within the EAA through the Cross and Bolles Canals are not simulated in the model.

Meeting Irrigation Requirement

If the total net excess volume of water for any EAA basin is negative, then an irrigation requirement for the basin has to be met from storage areas outside the basin. Currently, only Lake Okeechobee is used to meet irrigation requirements in the EAA. Deliveries to meet irrigation requirements are limited by conveyance capacities of the primary canals in the EAA. Likewise, supply-side management (SSM) may be imposed during periods of low lake levels. During implementation, SSM determines, at the beginning of each week, the daily allocation, i.e., portion of irrigation demand that will be allowed to leave the lake, for the entire LOSA which includes the EAA. Any irrigation requirement not met, due to conveyance limitations and/or limits set by SSM, will result in a uniform reduction in water levels for all grid cells in the appropriate destination EAA basin/s. On a given day, all EAA basins may not have irrigation requirements simultaneously.

The discussion of EAA canal conveyance is given next. Supply-side management was presented in detail in Sec. 3.2. Matching historical runoff (drainage) and demand (supplemental irrigation) are the primary goals in the EAA calibration (refer to Sec. 4.1). The full set of calibration/verification plots for the EAA can be found in Appendix E.

EAA Canal Conveyance

Three important issues need to be considered when dealing with EAA canal conveyance capacities:

1. If the stage in Lake Okeechobee is above regulation, how much water can be moved south through the EAA canals?

2. What quantities of water can be delivered down to LEC service areas from the lake through the EAA canals?

3. In order to guide decision-makers in formulating a strategy for making environmental releases to the Everglades, how much flow capacity do the existing EAA canals provide in routing lake water and EAA runoff to the south, and what improvements can be made to increase this capacity?

All questions can be addressed, at least numerically, if a hydraulic routing analysis is performed between the delivery point (Lake Okeechobee) and the destination points (Water Conservation Areas and Lower East Coast Service Areas). As mentioned earlier, the typical canal routing procedure in the model is a simple mass balance approach where the slope of the hydraulic grade line (water surface profile) is assumed to be constant. A modified procedure is used for the major EAA conveyance canals where the slope of the water surface is allowed to vary with time without actually calculating the change in storage within the canal.

First, in order to simulate the flows from the lake through the EAA and into WCAs and LECSAs, maximum allowable flows have to be defined. These thresholds vary depending on the conveyance canal (upstream structure, downstream structure, and canal itself) under consideration. Design capacities of individual facilities overestimate the capacity of the entire conveyance canal because: 1) total system capacity depends on the hydraulic interactions of all components of the conveyance canal; and 2) control over allowable flows in the EAA are subject to day-to-day decision making processes. An alternative approach is discussed next.

An analysis of historical flows through the major EAA canals (Miami, North New River, Hillsboro and West Palm Beach) reveals that the actual amount of regulatory flows released from the lake and the actual magnitude of agricultural runoff removed from the EAA were rarely close to the design capacity of the canals (Trimble, 1995b). In order to establish realistic allowable flows through these canals consistent with historical data, a seasonal average percentage of design discharge (Q_{design}) is used to define each EAA canal conveyance capacity in the model (Table 3.3.4).

Table 3.3.4 Allowable Percentage of Design Discharge Through the Major EAA Conveyance Canals (source: Trimble, 1995b)

EAA Conveyance Canal	Q_{design} (cfs)	Dry Season Percentage	Wet Season Percentage
Miami Canal	2,000	75%	50%
NNR-Hillsboro Canal	2,400	80%	50%
West Palm Beach Canal	950	65%	50%

These percentages are then applied to lake water pass-through/flowthrough calculations in the following manner. Due to the nature of wet season rainfall which often occurs in sudden heavy outbursts, the percentages associated with the wet season are more strict than those for the dry season (Trimble, 1995b).

During the wet season, when lake stage is above regulation, the maximum amount of water Q_{max} that can be released from the lake and delivered south to the WCAs via EAA canals can be calculated as

$$Q_{max} = \min [\ \text{neutral\_case},\ \text{percent\_wet} * \text{design\_discharge}\ ] - \text{runoff} \qquad (3.3.24)$$

where neutral case will be defined later. Flowthrough capacity during water supply conditions, on the other hand, can be defined as

$$Q_{max} = \min [\ \text{neutral\_case} - \text{demand},\ \text{percent\_wet} * \text{design discharge}\ ] \qquad (3.3.25)$$

During the dry season, two other empirical relationships can be defined for regulatory release and water supply release conditions:

$$Q_{max} = \min [\ \text{neutral\_case} - \text{runoff},\ \text{percent\_dry} * \text{design\_discharge}\ ] \qquad (3.3.26)$$

and

$$Q_{max} = \max [\ \text{neutral\_case} - \text{demand},\ 0.0\ ]. \qquad (3.3.27)$$

It must be emphasized that the above formulas for computing maximum allowable flows through the major EAA conveyance canals are empirical in nature. They reflect the field operators' preferences as they adapt to real day-to-day hydrologic conditions. Therefore, Eqs. (3.3.24 through (3.3.27) include the subjectivity involved in operating major structures in the EAA. Needless to say, the values shown in Table 3.3.4 should be reevaluated from time to time by analyzing more recent historical flow data at the major inlet and outlet structures in the EAA. An analysis similar to that presented in Trimble (1995b) should be performed to verify the applicability of Eqs. (3.3.24)-(3.3.27) on a regular basis.

The definition and derivation of the neutral_case condition is discussed next. Neutral_case refers to the pass-through/flowthrough capacity during no lateral flow conditions (no runoff and no demand) within the EAA. Given an EAA conveyance canal with upstream and downstream controls, e.g. S-354/Miami Canal/S-8, there exists a unique combination of upstream stage (S-354_HW), downstream stage (S-8_TW) and canal profile (along the Miami Canal) that corresponds to the maximum flow of water from the source (Lake Okeechobee) to the destination (WCA-3A). The neutral case condition is described by this situation assuming no lateral withdrawals due to irrigation and no lateral inflows due to runoff exist. A four-step procedure was followed to define neutral case conditions for all major conveyance canals in the EAA. They are:

1. Collect cross-sectional information (dimensions and Manning's *n* coefficients) required for a backwater analysis for all major canal reaches in the EAA.
2. Given a range of downstream stages and steady-state discharges perform backwater computations using HEC-2 (USACE, 1990) for all canal reaches (Gee and Jenson, 1995). Assemble the downstream stage, upstream stage and discharge information in tabular form.
3. Gather rating curve information for all structures separating the same canal reaches.
4. Write computer code to determine one of the following variables: downstream stage, upstream stage or discharge, given the values of the other two variables for any canal reach-structure configuration. Figure 3.3.5 shows all types of configurations where neutral case conveyance calculations are performed in the model. Italicized words refer to the specific program subroutines or functions that perform the calculations. For example, given lake stage and S-8 pump headwater, function *us_flow* is executed [Fig. 3.3.5(c)] when the pass-through discharge along the existing Miami canal is required. Function *usus_flow* is executed, instead, if the canal configuration is modified to include an intervening diversion structure (to the proposed STA3&4) along the Miami canal [Fig. 3.3.5(d)]. This step uses the key assumption in this approach: a known water surface profile provides a unique discharge through a specific canal reach-structure configuration. Since the model is not concerned with what happens internally within the EAA, specification of headwater (lake stage) and tailwater (downstream of EAA) conditions is sufficient to determine neutral_case flows. The model adjusts the headwater and tailwater conditions at appropriate canal reaches and intermediate structures in response to runoff or demand conditions in the EAA.

In summary, the neutral_case (no-runoff or no-demand condition) discharges or conveyance capacities are obtained in the model as a series of look-up tables generated from multiple HEC-2 runs for each canal, covering a wide range of flows, and upstream and downstream stages. Table 3.3.5 lists some properties of the nine EAA canal reaches where look-up tables were generated for and used in calculating conveyance capacities through the EAA.

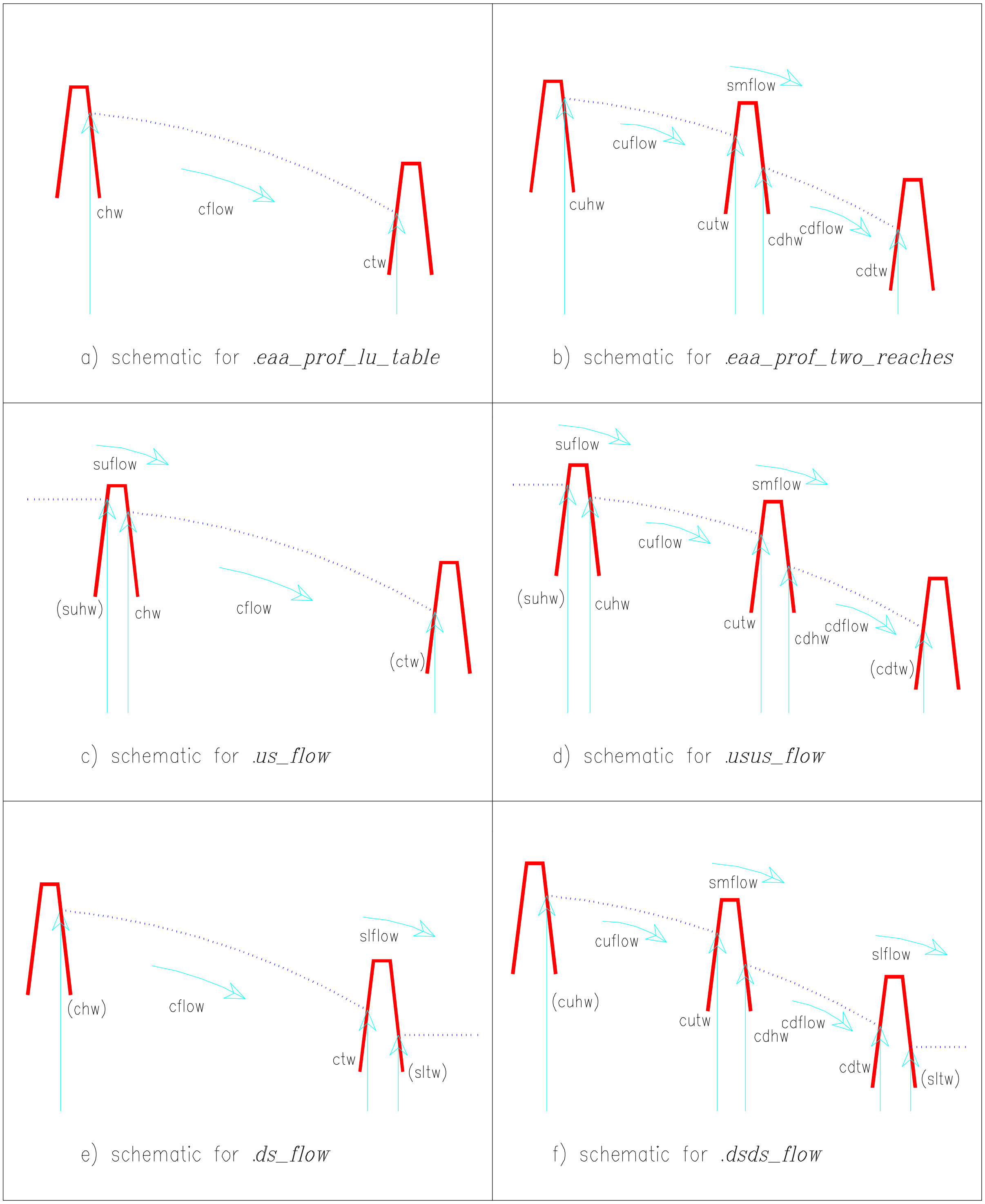
Table 3.3.5 Some Physical Properties of the Eight EAA Canal Reaches Used in Calculating Conveyance Capacities Through the EAA

EAA Canal	Upstream Reference Stage	Downstream Reference Stage	Length (mi)
Miami	LOK stage	S8_TW	26.2
North New River	LOK stage	S7_TW	28.6
Hillsboro	S351_TW	S6_HW	23.7
West Palm Beach	S352_TW	S5A_HW	20.8
Miami* (upper reach)	S354_TW	S8NEW_HW	19.3
North New River* (upper reach)	S351_TW	S7NEW_HW	24.6
North New River* (lower reach)	S7NEW_TW	S7_HW	4.0
Miami* (lower reach)	S8NEW_TW	S8_HW	6.9

* refers to future base scenario with proposed Stormwater Treatment Areas in operation, and the Miami and North New River canals are both split into upper and lower reaches

Above-Ground and Below-Ground Reservoirs

Water-holding facilities or reservoirs serve a variety of functions within the EAA. In the model, reservoirs are classified as above-ground or below-ground. The Holey Land can be considered as an above-ground reservoir that acts as a wetland preserve. Examples of existing above-ground reservoirs outside the EAA used in the model are the West Palm Beach Catchment Area and the Indian Trails Water Control District reservoir. Proposed above-ground reservoirs in the EAA are the Stormwater Treatment Areas (STAs) whose function is to improve the water quality of runoff generated from the EAA as well as releases from Lake Okeechobee. Thus, above-ground reservoirs can be further classified into STA and non-STA reservoirs. Proposed Aquifer Storage and Recovery (ASR) systems, on the other hand, are examples of below-ground reservoirs which are intended to store lake water or EAA runoff for later use to enhance water supply needs (primarily irrigation) during drier times within the EAA. Initial design and construction work on the STAs are currently under way. The enormous significance of STAs and ASRs warrant a separate discussion of these types of reservoirs.



note: Variables in parentheses are known or fixed values.

Figure 3.3.5 Canal-Structure Configurations Used in Calculating Canal Conveyance Capacities for the Everglades Agricultural Area Algorithm in the South Florida Water Management Model

Stormwater Treatment Areas

The objectives of STAs (Fig. 3.3.6) are summarized as follows.

1. To resolve the various outstanding issues surrounding the proposed Surface Water Improvement and Management (SWIM) Plan for the Everglades (SFWMD, 1992) as part of a technical plan which was formulated and, subsequently, revised (Burns and McDonnell, 1994).
2. To reduce long-term average concentration of total phosphorus from EAA runoff to the Everglades Protection Area (EPA) to an interim goal of 0.05 g/m^3.
3. To restore the hydroperiod in the northern areas of WCA-2A and WCA-3A.
4. To increase quantity and improve quality of water retained in the Everglades system through redirection of runoff from C-51W basin.

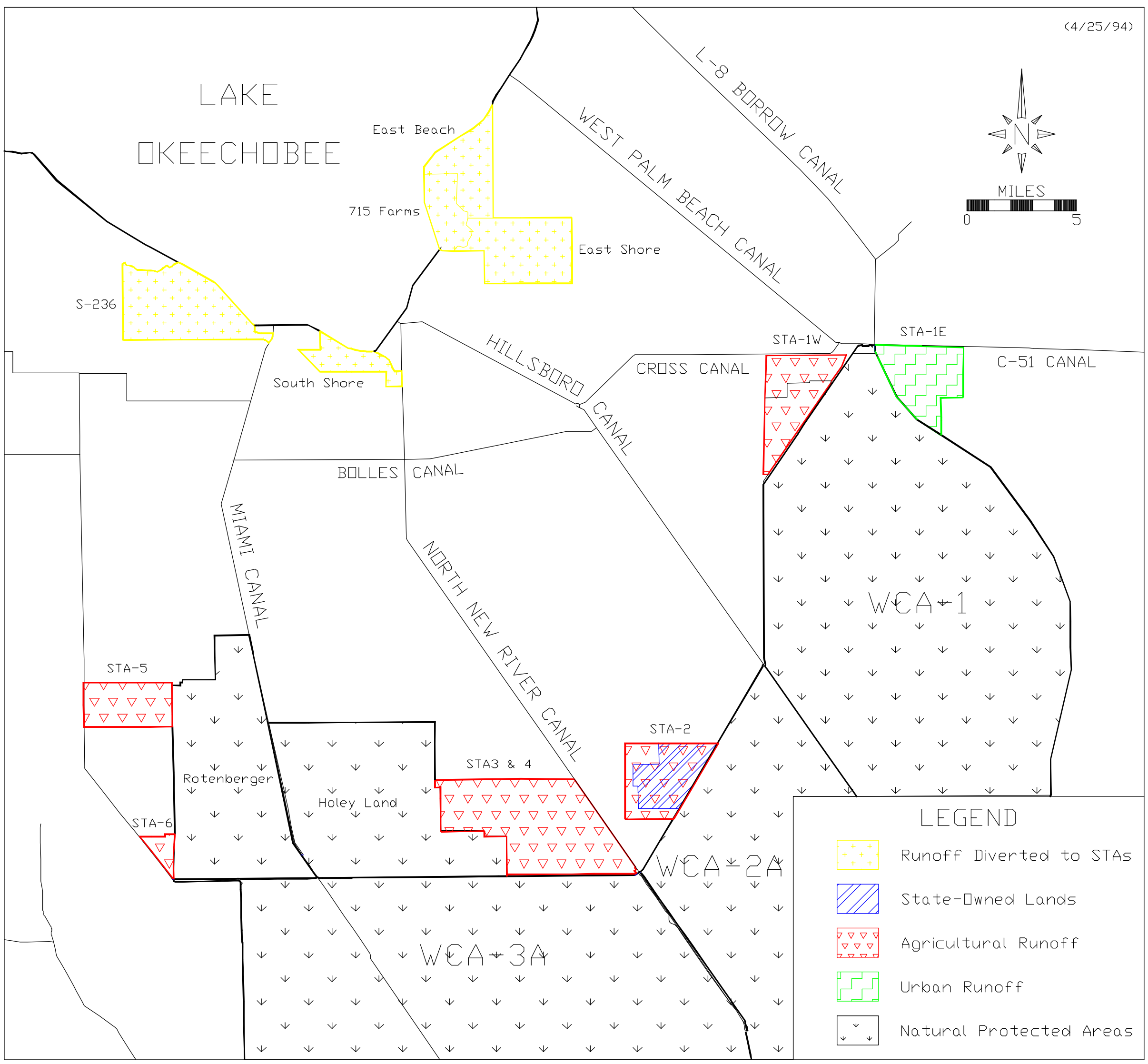


Figure 3.3.6 Location of the Proposed Stormwater Treatment Areas

5. To restore the hydroperiod in the Rotenberger Tract with water of suitable quality.
6. To reduce localized water quality problems in Lake Okeechobee associated with discharges from special drainage districts adjacent to the lake such as "298" Districts and S-236 basin.

Figure 3.3.7(a) shows a schematic of how the SFWMM sees the current operation of the system within and around the EAA while Fig. 3.3.7(b) depicts the same area after all proposed STAs are in place. The definition of the variable names shown in these figures are in Appendix I.

The general assumptions used in implementing STAs in the model are:
1. A mass balance approach using minimal input data is used in calculating discharge in and out of STAs. These discharges are subject to structure and canal conveyance capacity constraints.
2. EAA Best Management Practices (BMPs) are simulated by increasing the upper limit of the soil moisture storage in the unsaturated zone for the cells in the EAA. This maximum is determined by trial and error.
3. Each STA is treated as a single reservoir.
4. The assumed operational water depths are as follows: minimum depth = 0.5 ft; desired mean depth = 2.0 ft; depth at which outflow begins = 1.25 ft; and maximum depth = 4.5 ft.
5. Water supply releases from Lake Okeechobee to LEC bypasses STAs and are, thus, untreated.
6. Inflows vary by location and condition as shown below.
   a. STA-1W:
      S-5A basin runoff from EAA minus up to 600 cfs that is diverted to STA-2.
      Environmental releases from LOK or BMP makeup water via WPB canal and S-352.
      Maximum inflow is 3,250 cfs-day.
   b. STA-1E:
      C-51W basin runoff through S-319.
      The difference between S-5A basin runoff from EAA and diversion to STA-2 in excess of 3,250 cfs-day.
      Maximum inflow is 1,550 cfs-day.
   c. STA-2:
      Up to 600 cfs of S-5A basin runoff.
      S-6 basin runoff via S-6 and proposed conveyance canal (Hillsboro).
      Runoff from East Beach, East Shore and 715 Farms basins.
      Environmental releases from LOK to WCA-2A, if any, or BMP makeup water via Hillsboro Canal.
   d. STA-3&4:
      Runoff from S-8 and S-3 basins (excludes US Sugar Southern Division Ranch).
      Runoff from the S-7 and S-2 basins.
      C-139 basin flows via G-136 and L-1E.
      Environmental releases from LOK, or BMP makeup water via S-354 and Miami Canal.
      Runoff from S-236 basin and South Shore.
      Lake Okeechobee regulatory discharges from S-354 to Miami canal and from S-351 to North New River Canal.

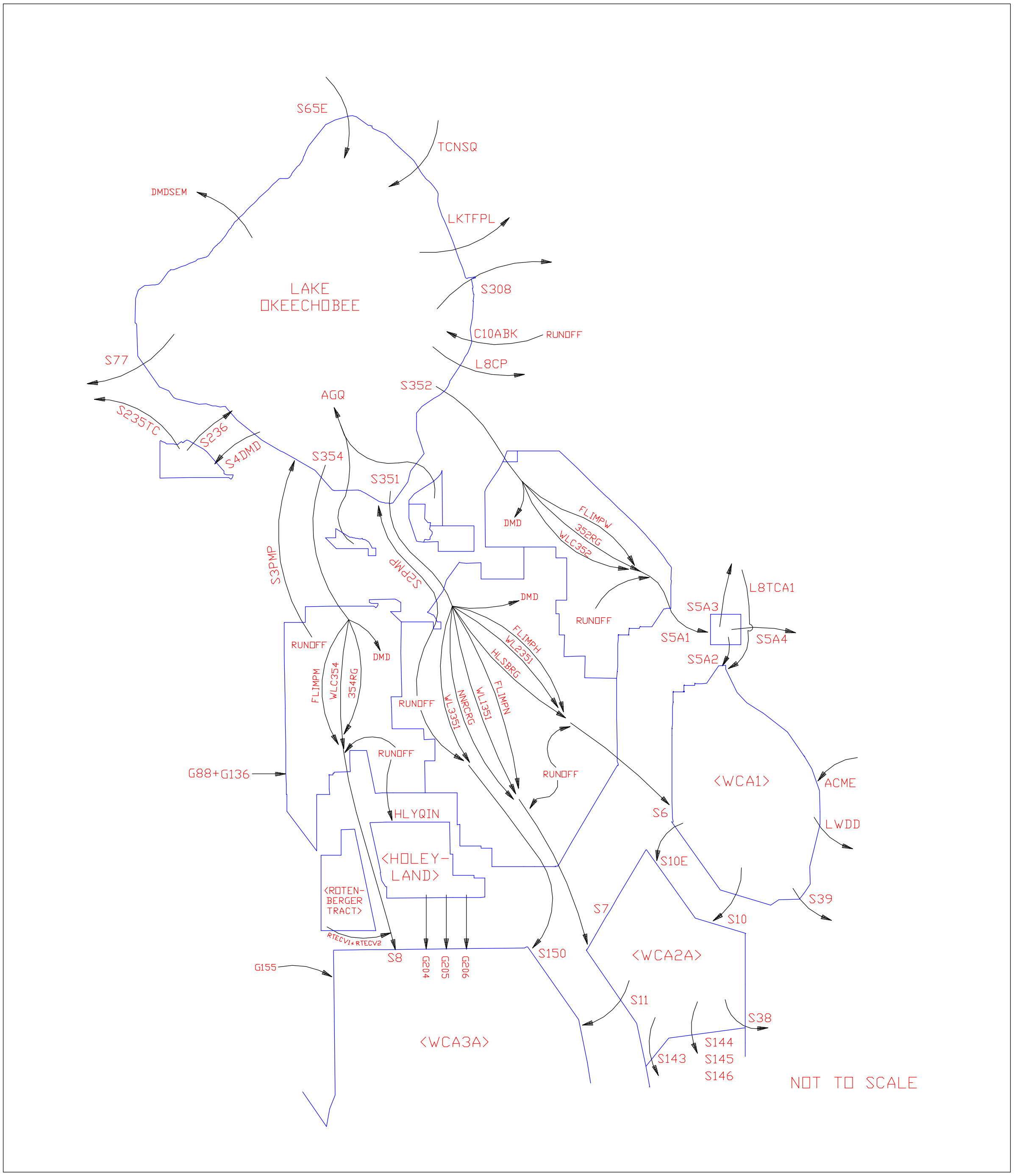


Figure 3.3.7(a) Flow Distribution Within and Around the Everglades Agricultural Area without the Proposed Stormwater Treatment Areas (current base condition) in the South Florida Water Management Model

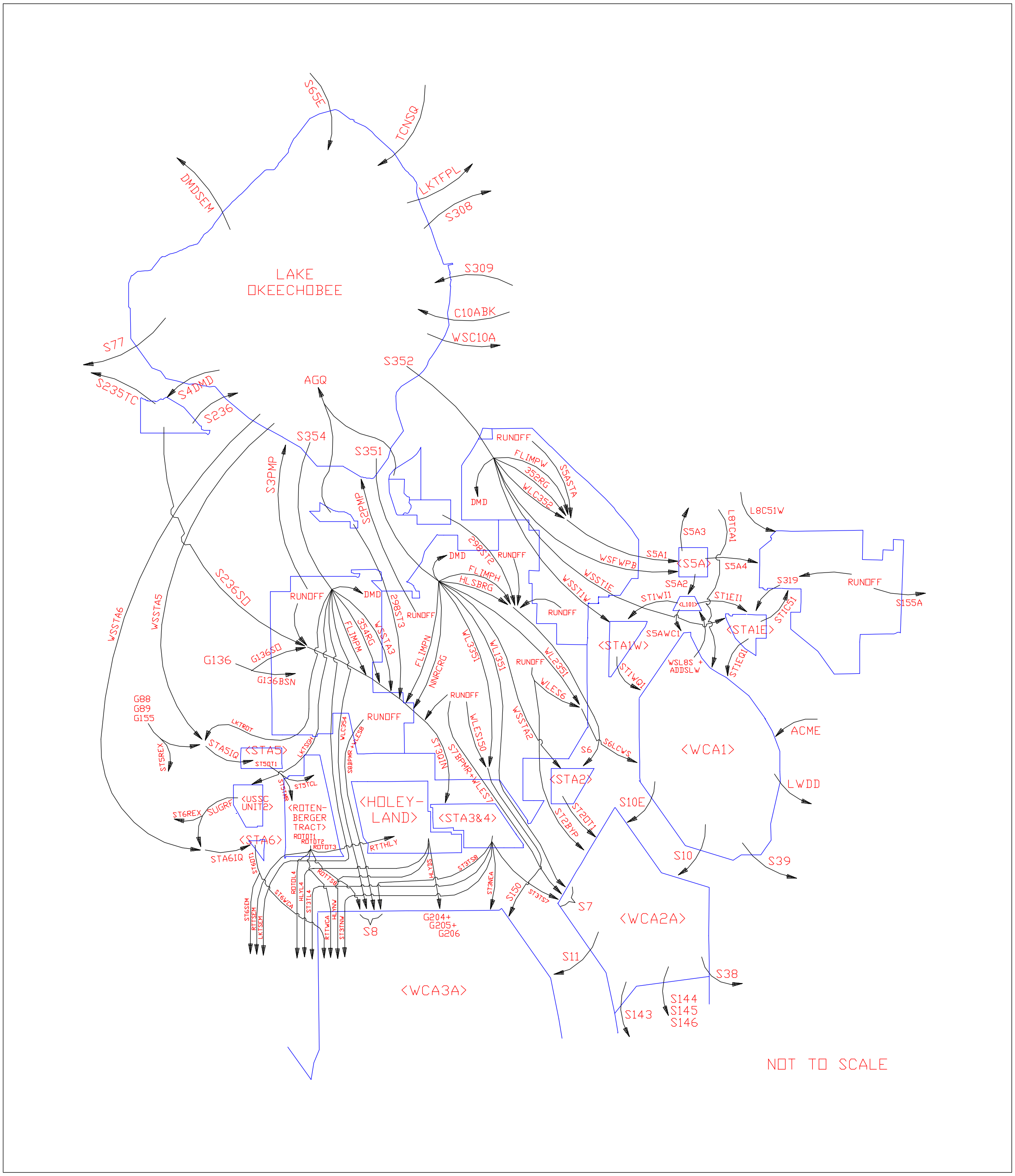


Figure 3.3.7(b) Flow Distribution Within and Around the Everglades Agricultural Area with the Proposed Stormwater Treatment Areas In Place (future base condition) as Implemented in the South Florida Water Management Model

e. STA-5:
65% of G-88, G-89 and G-155 flows from C-139 basin.
f. STA-6:
Runoff from US Southern Division Ranch plus 35% of G-88, G-89 and G-155 flows from C-139 basin.
g. Rotenberger:
STA-5 outflow.

All inflows are subject to canal conveyance capacities and/or structure capacities.

Approximately 40,000 acres of EAA land will be converted into STAs (STA-1W, STA-2, STA-3&4, STA-5, and STA-6). The site for the Everglades Nutrient Removal (ENR) project is the prototype for STA-1W. A summary of the general operating considerations for STAs in the EAA is given in Table 3.3.6.

Table 3.3.6 General Operating Considerations for STA-type Reservoirs in the EAA Simulation within the South Florida Water Management Model

Purpose	Source of Water	Rule for Outflow
• Stormwater treatment to reduce phosphorus loading into Everglades • Hydroperiod enhancement in WCAs by improvement of volume, timing, and distribution of flow to the Everglades	• EAA or other basin runoff • LOK regulatory releases • LOK environmental water	• Regulate outflow such that average depth of water in the Stormwater Treatment Area is approximately equal to 2.0 ft

Two options exist in the SFWMM that affect the volume of water treated in STA-3&4, STA-2 and STA-1W. These options refer to the way demands are being met in the Everglades and urban areas. The operations of Lake Okeechobee, EAA, Water Conservation Areas, and Lower East Coast are closely related. Although this section focuses on the EAA, a discussion of some operational rules applicable to the WCAs as well as the Lower East Coast may be necessary at this point in order to explain various options in the model. These options are:

1. "No Priority" Option:
Under this option, the Everglades will receive (for environmental restoration purposes) all available EAA runoff ahead of the Lower East Coast (for water supply purposes) by virtue of the former's closer proximity to the EAA. The amount to be delivered to the Everglades is limited by the canal conveyance capacities within the EAA as well as operational constraints associated with intervening retention/detention areas such as STAs, if any. Of course, such deliveries will only occur in the model if some stage (or flow) targets are defined by the user

for the Everglades; otherwise, all available EAA runoff will be used to meet water supply needs in the LEC.

The first source of water that meets LEC demands are the Water Conservation Areas. If the runoff generated from the EAA exceeds the remaining LEC demands after the appropriate Water Conservation Area has made its release, all EAA runoff is pumped into the appropriate STA, subject to conveyance constraints. EAA runoff in excess of the STA pump capacity and conveyance capacities within the EAA bypasses the STAs, remains untreated, and still routed south to alleviate flooding within the EAA.

If the runoff generated from the EAA is less than or equal to the remaining LEC demands, i.e. after the appropriate WCA has made its release, all EAA runoff bypasses the appropriate STA and are subject to EAA conveyance constraints. Water sent south to meet LEC Service Areas demands is all untreated.

2. Everglades/LEC Priority Option:
In this option, the user specifies a fraction, FRCT, of the total volume of water available from EAA runoff that will be used directly, i.e., untreated, to meet LEC service area demands as required. This fraction can range from 0.0 to 1.0; environmental demands get priority with a fraction equal to 0.0 while LEC service area demands get priority with a fraction equal to 1.0. In general, what bypasses the STAs and meets LEC service area demands equals FRCT multiplied by the total available water. Conversely, what gets treated by the STAs and meets environmental demands equals (1.0-FRCT) multiplied by the total available water.

EAA Reservoirs Other Than STAs

Table 3.3.7 shows a summary of general operating considerations if a non-STA-type reservoir is being simulated. The reader must be aware that only the Holey Land, which behaves like an above-ground reservoir and modeled as such in the SFWMM, currently exists in the EAA. The information in Table 3.3.7 is just an example of the many ways to incorporate such facilities in the model. The associated operating rules are subject to constant revisions and enhancements.

If an STA and a non-STA reservoir both exist in same EAA basin, the model assumes that the non-STA reservoir receives excess runoff/LOK regulatory releases first; the remainder of the excess water goes to the STA reservoir for treatment. The model assumes all reservoirs to have vertical walls. It accounts for differences in the actual area of the reservoir and the area represented by the grid system, i.e., multiples of four sq. miles. Since rainfall and evapotranspiration depths are assumed to occur uniformly for each model grid cell, their effect on reservoir stage is transformed using a proportionality factor relating reservoir area and the area of the grid cell/s where the reservoir is located. For a given reservoir,

$$sfactor = \frac{tot\_reservoirarea}{(no.\ of\ grid\ cells) \bullet (gridcellarea)}$$

Table 3.3.7 General Operating Considerations for non-STA-type Reservoirs in the EAA Simulation within the South Florida Water Management Model

Non-STA-Type Reservoir Classification	**Source of Water**	**Purpose**	**Rules for Outflow**
Reservoir without ASR (e.g., proposed reservoir in the Talisman property within EAA)	● Excess EAA runoff ● LOK regulatory releases	Store excess water and later meet irrigation requirements in EAA	Reservoir used first to meet EAA irrigation requirements, then LOK meets the remainder
Reservoir with ASR wells (e.g., proposed reservoirs in EAA)	LOK when lake stage is within ASR injection zone (refer to Fig. 3.3.8) and no LEC or environmental demands exist	Deep aquifer storage of excess water for later retrieval to meet irrigation requirements in EAA (Water Supply Enhancement)	If LOK stage is above ASR water supply line, LOK used first to meet irrigation requirements. ASR meets remainder; otherwise ASR first, then LOK meets remainder.
Holey Land	Miami Canal Basin runoff subject to 11.0' 13.0' schedule in Holey Land	Hydroperiod Restoration: achieve more natural flow pattern into WCA-3A	**Wet season:** Flow through outlet structure with culverts open full. **Dry season:** Hold water up to 2.0 ft depth before making a release. Culverts open full when Holey Land stage is 1 ft above inflow schedule.

The change in reservoir stage within time step t is approximated using the following equation:

$$\Delta reservoirstage_t = \frac{RF_t - ET_t + LSEEP_t + GWIN_t}{sfactor} - [RF_t - ET_t] \bullet [1.0 - sfactor]$$

where:

RF_t = rainfall into grid cell;
ET_t = evapotranspiration out of grid cell;
$LSEEP_t$ = levee seepage into grid cell; and
$GWIN_t$ = net groundwater inflow to grid cell.

Reservoir stage is used in determining available storage in the reservoir. It is also the basis for calculating discharges through inlet and outlet structures (pumps and weirs).

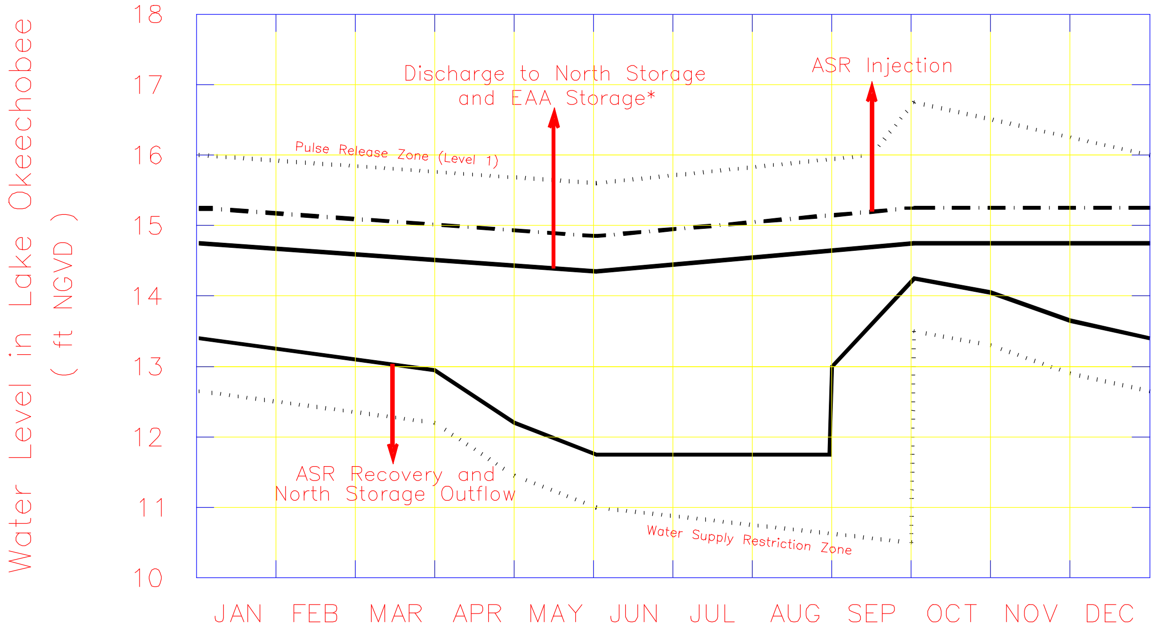
Aquifer Storage and Recovery

Aquifer Storage and Recovery or "Aquifer storage recovery (ASR) is a water management technology in which water is stored underground in a suitable aquifer through a well during times when the water is available and recovered from the same well when needed." (Pyne, et al., 1996). ASRs are sometimes referred to as deep aquifer storage or subsurface storage and retrieval systems. Several ASR demonstration projects revealed that this storage/supply augmentation alternative can be viable within the Lower East Coast of Florida. ASR recoverability in South Florida was studied using digital modeling (Merritt, 1983). The South Florida Water Management Model simulates ASRs by performing a simple water budget on the mound of injected water below the surficial aquifer, taking into consideration inefficiencies in injection and withdrawal phases of the operation, and basically treating an ASR as a regular reservoir with one obvious advantage: ASRs do not lose water via evapotranspiration which is significant in above-ground reservoirs.

Other advantages of ASRs are: (1) natural artesian pressure can be utilized to recover injected water and thus minimize pumping cost associated during withdrawals; (2) it requires minimum amount of land for construction of associated facilities; and (3) water quality can potentially improve. The disadvantages of ASRs are: (1) the permitting process may take a long period of time; and (2) significant capital outlay during construction and operation are to be expected.

ASRs can potentially be placed anywhere within the modeling domain of SFWMM. For ASRs in the EAA, the lake schedule can be enhanced to include an ASR injection zone where lake water, in addition to local runoff, can be injected into the ASR for later withdrawal in order to meet EAA demands. Storage reservoirs north of Lake Okeechobee (North Storage), in the Caloosahatchee and St. Lucie basins, and in the EAA in addition to Lake Okeechobee ASRs are proposed to increase the capacity of the hydrologic system to better meet the water management objectives associated with flood protection, water supply, and environmental enhancement (USACE, 1998).

Figure 3.3.8 summarizes the operation of LOK for reservoir storage and retrieval as well as ASR. In general, discharge to North Storage and EAA storage occurs before ASR injection. If Lake Okeechobee stage is above the Pulse release zone (level 1) line or if Lake Okeechobee stage is forecasted to be above the “Discharge to Storage” line within the next three months, then Lake Okeechobee water is diverted to North Storage and EAA storage when capacity exists. Similarly, if Lake Okeechobee stage is above the Pulse release zone or if Lake Okeechobee stage is forecasted to be above the “ASR Injection” line within three month, Lake Okeechobee water is injected into ASR wells. (The model’s LOK stage forecasting capability was derived from an application of artificial neural networks to predict LOK inflows by Zhang and Trimble (1996).) For recovery during the dry season, water is retrieved from North Storage and ASR wells if Lake Okeechobee stage is currently below, or is forecasted to be below in six months, the “ASR Recovery and North Storage Outflow” line. During the wet season water is retrieved if LOK stage is below the “ASR Recovery and North Storage Outflow” line and if the climate based inflow forecast is less than 1.5 million acre-ft for the next six months. Again, the reader is reminded that these operational strategies are continuously evolving with time as they go through brainstorming, field-testing and rule-making process.



*note: Discharge to North and EAA Storage if Lake Okeechobee Stage is forecasted to be above "Discharge to . . . Storage" line, or if stage is above Pulse Release Zone (Level 1) line.

Figure 3.3.8 Trigger Lines for Proposed Lake Okeechobee Aquifer Storage and Recovery, and North Storage as Used in the South Florida Water Management Model